

LOCALIZATION TECHNIQUE BASED ON DUAL-FREQUENCY DOPPLER
RANGING ESTIMATION

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*To my beloved mother, father, sisters, grandpa, family and friends for their continuous
never ending support.*

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ABSTRACT

Positioning awareness plays an important role in modern applications such as internet of thing (IoT) and intelligent transportation system (ITS). One of the commonly used positioning techniques is trilateration as it estimates the location of a blind device or node by using the distance from several other devices or anchor nodes. The ranging technique used to obtain distance information is a crucial step to provide high accuracy in location estimation. Dual-frequency Doppler radar (DFDR) ranging technique has been widely used in radars and radio frequency identification (RFID) applications. In radar application, this technique requires a closed-loop communication link to estimate distance and has not been exploited in single radio frequency transmission. In this thesis, a ranging technique not requiring a closed-loop communication link named one-way forward communication link dual-frequency Doppler (DFD) ranging technique is introduced. The performances of the DFD distance estimation were analysed using simulations and experimental measurements. In the DFD experiment, the anchor node transmitted two different frequencies with a certain frequency separation. The blind node captured the received signal, and the phase difference was extracted and unwrapped using offline processing system. The phase difference between the two received signals was used for DFD ranging estimation before being applied to locate the position of the blind node through trilateration method. Software defined radio (SDR) platform using GNU radio and universal software radio peripheral (USRP) was used to develop the localization system. The experimental results showed that DFD ranging technique can deliver up to 84% distance estimation improvement in comparison to conventional receive signal strength (RSS) ranging technique. In conclusion, the proposed DFD ranging technique is a promising positioning solution for future applications such as IoT and ITS.

ABSTRAK

Kesedaran tentang kedudukan memainkan peranan penting dalam aplikasi moden seperti *internet of thing* (IoT) dan sistem pengangkutan pintar (ITS). Salah satu teknik penentuan kedudukan yang biasa digunakan ialah penigasegian yang menganggarkan lokasi peranti atau nod sasaran dengan menggunakan jarak dari beberapa peranti atau nod utama. Teknik penentuan jarak yang digunakan untuk mendapatkan maklumat jarak adalah satu langkah penting dalam menentukan kedudukan nod secara tepat. Teknik radar dwi-frekuensi Doppler (DFDR) ini digunapakai secara meluas dalam aplikasi radar dan pengecaman frekuensi radio (RFID). Dalam aplikasi radar, teknik ini memerlukan komunikasi gelung tertutup untuk menentukan jarak dan konsep ini kurang diguna pakai dalam perhubungan frekuensi radio sehala. Dalam tesis ini, teknik penentuan jarak yang tidak memerlukan komunikasi gelung tertutup yang dinamakan sebagai dwi-frekuensi Doppler (DFD) bagi komunikasi satu hala diperkenalkan. Prestasi penentuan lokasi menggunakan teknik penentuan jarak DFD dianalisis berdasarkan simulasi dan eksperimen. Dalam eksperimen DFD, nod utama menghantar dua frekuensi yang berbeza dengan perbezaan antara frekuensi yang tertentu. Nod sasaran menerima isyarat yang dihantar oleh nod utama dan data diekstrak di mana data perbezaan fasa akan diproses menggunakan sistem pemprosesan di luar talian. Perbezaan fasa antara kedua-dua isyarat yang diterima akan digunakan dalam persamaan jarak DFD sebelum digunakan untuk mencari lokasi atau kedudukan nod sasaran dengan menggunakan kaedah penigasegian. Platform radio tentuan perisian (SDR) yang terdiri daripada GNU radio dan persisian radio perisian universal (USRP) digunakan untuk membina sistem penentuan lokasi. Keputusan eksperimen menunjukkan bahawa teknik penentuan jarak DFD mampu memberikan penganggaran jarak dengan peningkatan sebanyak 84% jika dibandingkan dengan teknik kekuatan isyarat terima (RSS). Kesimpulannya, teknik penentuan jarak DFD yang dicadangkan menjanjikan penyelesaian penentuan jarak bagi aplikasi masa hadapan seperti IoT dan ITS.

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LIST OF ABBREVIATIONS

ADC	-	Analogue Digital Converter
AoA	-	Angle of Arrival
CR	-	Cognitive Radio
CRT	-	Chinese Remainder Theorem
DAC	-	Digital Analogue Converter
DFD	-	Dual-Frequency Doppler
DoA	-	Direction of Arrival
ESPRIT	-	Estimation of Signal Parameter via Rotational Invariance
EDSM	-	Enhance Dynamic Spectrum Management
FFT	-	Fast Fourier Transform
FPGA	-	Field Programmable Gate Array
GPS	-	Global Positioning System
GRC	-	GNU Radio Companion
GPSDO	-	GPS Disciplined Oscillators
IoT	-	Internet of Things
ITSs	-	Intelligent Transportation Systems
ISM	-	Industrial, Scientific, Medical
LOS	-	Line of Sight
LSE	-	Least Square Estimator
MLE	-	Maximum Likelihood Estimator
MUSIC	-	Multiple Signal Classification
MIMO	-	Multiple Input Multiple Output
PPS	-	Pulse per Second
PLE	-	Path Loss Exponent
PU	-	Primary User
PDoA	-	Phase Difference of Arrival
RIPS	-	Radio Interferometric Positioning System
RMSE	-	Root Means Squared Error

RSS	-	Received Signal Strength
RF	-	Radio Frequency
RFID	-	Radio Frequency Identification
RTT	-	Round Trip Time
SAR	-	Synthetic Aperture Radar
SU	-	Secondary User
SNR	-	Signal to Noise Ratio
SDR	-	Software Define Radio
ToA	-	Time of Arrival
TDoA	-	Time Difference of Arrival
USRP	-	Universal Software Radio Peripheral

LIST OF SYMBOLS

P_r	-	Power Receive
D	-	Distance
P_t	-	Power Transmit
G_t	-	Gain Transmit
G_r	-	Gain Receive
L	-	Loss that not related to propagation loss
λ	-	wavelength of transmitted signal
P_L	-	Path Loss
n	-	Path Loss Exponent
X	-	Shadowing effect
d_{los}	-	Distance of LOS signal
d_{gr}	-	Distance of the reflected signal
h_t	-	Transmitter antenna height
h_r	-	Receiver antenna height
r	-	Reflection coefficient
V	-	Velocity of the signal
t	-	Time
R_x	-	Receiver (blind node)
T_x	-	Transmitter (anchor node)
f_i	-	Frequency of the i^{th} signal
n_t	-	noise
ϕ_i	-	Phase of the i^{th} signal
Δf_{2-1}	-	Frequency separation/ difference
$\Delta \phi_{2-1}$	-	Phase difference
f_s	-	Frequency Sampling
N	-	FFT size
H_0	-	Target is idle
H_1	-	Target is active

f_c	-	Centre frequency
k	-	positive integer
γ	-	Decision for Energy detection frequency scanning

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CHAPTER 1

INTRODUCTION

1.1 Overview

Positioning awareness has a huge potential in wide variety research field that involves the localization, tracking, and identification of humans, object, and vehicle. This location awareness computing is expanding in numerous modern applications, such as personal and public navigation, security, healthcare, entertainment, and military. Today, with an advanced technology known as Internet of Things (IoT), the feasibility of employing the localization via the Internet is on demand. For this reason, tracking ability in real time is often anticipated. Following this, another current development of Intelligent Transportation System (ITS) has been established, which aims to support a wide range of application related to different modes of transportation and traffic management such as navigation, vehicle routing and location based service, hence increases the requirement of robust localization techniques.

There are different ways to get the location of an object, such as by using Global Positioning System (GPS). However, GPS is inefficient in term of cost effective approach and unviable for a specific condition, especially when there is no Line of Sight (LOS) between target or blind node and GPS satellite, also known as an anchor node [1]. Due to this limitation, different ranging technique has been developed over a decade with different approaches such as Receive Signal Strength (RSS) and Time of Arrival (ToA).

The ranging technique is the key essentials in providing high accuracy location estimation. For instance, in trilateration localization concept, the distances information between the anchor nodes and the blind node are required before the location of the blind node can be estimated. From the existing ranging techniques, it has been reported that the phase-based ranging technique is more robust in estimating the distance [2,

3, 4, 5, 6, 7, 8, 9, 10, 11, 12]. The phase differences of the return signal in phase-based ranging technique are exploited to estimate the distance of the target which is commonly applied in radar applications.

The Radio Frequency (RF) approach has been proposed to provide cheaper and robust localization solution compared to infrared or ultrasound approach [13]. Previously, the development of Software Define Radio (SDR) platform builds opportunities for a cost effective ranging estimation resolution. However, in the field of localization, the usage of SDR platform has not been fully investigated on the distance estimation, especially in phase dependent estimation algorithm.

1.2 Problem Statement

As mentioned before, localization plays an important role in the current technology development, such as IoT and ITS. The location information can assist various system functionalities, such as location identification of an event of interest, especially during rescues and disasters mission. One of the examples in rescues and disasters mission is when the structure collapsed due to the earthquake. Providing these high-risk applications, requirements that needed to be fulfilled are cost effective and low complexity system.

Several research on ranging technique developments have been studied to design a robust localization technique, which is considered as the main factor affecting localization accuracies. Phase-based ranging that employs phase difference between two received signals is one of the robust ranging techniques that has been applied in a two-way communication system such as radar and Radio Frequency Identification (RFID) system [9, 10, 14, 15, 16]. Seemingly, the phase-based ranging technique has the potential via one-way forward link communication system. In addition, the SDR platform provision, especially on Universal Software Radio Peripheral (USRP), has not been fully utilized in this localization field.

In this thesis, localization technique is proposed by implementing Dual-Frequency Doppler (DFD) ranging method that exploits the phase difference of the arriving signals to estimate distance information. The research expectation is to provide reliable accuracy in distance and localization estimation.

1.3 Research Objective

The research objective of this thesis are as follows:

1. To propose localization technique using Dual-Frequency Doppler (DFD) ranging estimation method.
2. To implement the proposed localization technique using Universal Software Radio Peripheral (USRP)
3. To evaluate and validate the performance of the proposed system through simulation and experimental work.

1.4 Scope of Work

Several assumptions are considered in the research development process. The experimental setup of the DFD ranging estimation was executed on Universiti Teknologi Malaysia (UTM) main soccer field near P19a building. The dual frequencies that were used during the experiment for transmission are predetermined and the frequencies are within the range of Industrial Scientific Medical (ISM) band, 2.4 GHz till 2.5 GHz. The equipment used for data measurements are USRP platform, GNU Radio system and Matlab for simulation. Two nodes are required for experimental setup, which is known as anchor node and blind node, used as a transmitter and receiver respectively. However, for each anchor node, two USRPs are needed to transmit two frequencies. Therefore, these USRPs are assumed to be synchronized with each other.

The modulation scheme is unnecessary since the anchor node only transmitting tone signals for distance estimation. Hence, this project research focuses on the study of the physical layer and the power transmitted within allowable limits provided by national regulation bodies. Last but not least, the data collection throughout research will be post-processing using Matlab to analyse the performance of distance and location estimation. It is assumed that blind node and anchor node are in the same coverage area and able to communicate with each other.

1.5 Contributions

The significant contribution of this project is the development of the range estimation using DFD ranging technique which evolving from the phase difference of RFID system arrival technique and the conventional ranging technique applied in a radar system. In this project, the proposed technique is suitable for a one-way forward communication link system instead of two-way communication as applied in RFID and Radar. This project also computes the location of the blind nodes based on the ranging estimation data obtained from the experimental work. However, this location of the blind nodes was constructed through simulation using collected database of range estimation.

Based on simulations, the proposed DFD ranging technique shows adequate accuracy in distance estimation under the influence of 15° variance of White Gaussian Noise with minimum error in distance estimation for 10 Mhz frequency separation is achieved 1.19 meter. The phase unwrapping technique known as Maximum likelihood estimation (MLE), Least Square Estimator (LSE) and Chinese Remainder Theorem (CRT) is proposed to improve distance estimation using DFD ranging technique. Following this, the minimum error in distance estimation through experiment achieved is 0.23 meters while by using Receive Signal Strength (RSS) ranging technique the minimum error achieved is 1.44 meters. In comparison with RSS technique in term of minimum error, DFD can provide better distance estimation with the same experiment configuration up to 84% improvement.

It is also worth mentioning that two conference paper already been published related to this research work such as “Ranging Estimation Using Dual-frequency Doppler Technique ” and “Phase Unwrapping Technique for Dual-Frequency Doppler Ranging Estimation ”.

1.6 Thesis Organization

Chapter 1 stated the background of the research, problem statement, objective, scope of work and contribution of the research.

Chapter 2 elaborates the fundamental background and relevant literature reviews on propagation studies, localization techniques, ranging techniques that are

used as references for phase unwrapping techniques. This chapter also discussed the improvement of DFD ranging technique. Lastly, general information on the platform used in this project is also provided.

Chapter 3 introduces the theory of the proposed ranging technique which is DFD ranging technique. The theory on data extraction technique using Fast Fourier Transform (FFT), phase unwrapping techniques and localization using trilateration technique is also discussed in depth.

Chapter 4 discussed the simulation and experimental implementation by using the related theory explained in Chapter 3 to achieve the research objectives of this project. The method used for this project is extensively explained with additional flowchart presentation.

Chapter 5 presents the result obtain from simulation and experimental work that discussed in Chapter 4. Then this result is further discussed in term of performance accuracy by comparing with other research works that applied the same approach. Then, the reason behind the degradation of the data from experiment compared to simulation data is elaborate. Chapter 5 presents the result obtained from simulation and experimental work that were discussed in Chapter 4. Results interpreted in term of performance accuracy by comparing with existing research works which use a similar approach. The data degradation factor from the comparison of actual and simulation data was elaborated.

Chapter 6 concludes the research findings and also provides the recommendation for future work.

Then, this DFD ranging technique can be implemented on the moving nodes since various applications especially transportation system is always moving.

This proposed technique can be investigated to be implemented in Wireless Sensor Network (WSN) since WSN is in the need of high accuracy localization system especially in disaster and rescue mission. Next, several frequencies separation pair can be used for distance estimation instead of using only two transmitted frequency at a time in this thesis. Beside that, this distance estimation system can be develop to estimate the distance between blind node and anchor node without the need for the post-processing that usually offline. Last but not least, the additional investigation can be carried out where experimental measurement can be perform at different time that have less signal traffic.

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